Estimating the Lidar Ratios of Modeled Aerosol Species to Help Inform Selection for Marine Aerosol Lidar Ratios in a Future CALIPSO Data Products Release

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103rd AMS Annual Meeting

12th Symposium on Lidar Atmospheric Applications

11 January 2023

The MAC Project for the MIRA Working Gro

- **MIRA**: Models, In situ, and Remote Sensing of Aerosols
  - A new forum that encourages interdisciplinary work and fosters international collaborations
  - 200+ members in 22 countries and growing
  - Currently consists of 4 projects but are seeking new projects. If interested, please contact the MIRA steering committee at https://science.larc.nasa.gov/mira-wg/contacts/

- **MAC:** Mapping Aerosol lidar ratios for CALIPSO
  - Lead: Greg Schuster (NASA LaRC)
  - Uses lidar ratio retrievals and measurements with aerosol types provided by global aerosol models to build global lidar ratio maps that can vary by season
  - These maps will be pertinent to the CALIPSO Version 5 extinction profile

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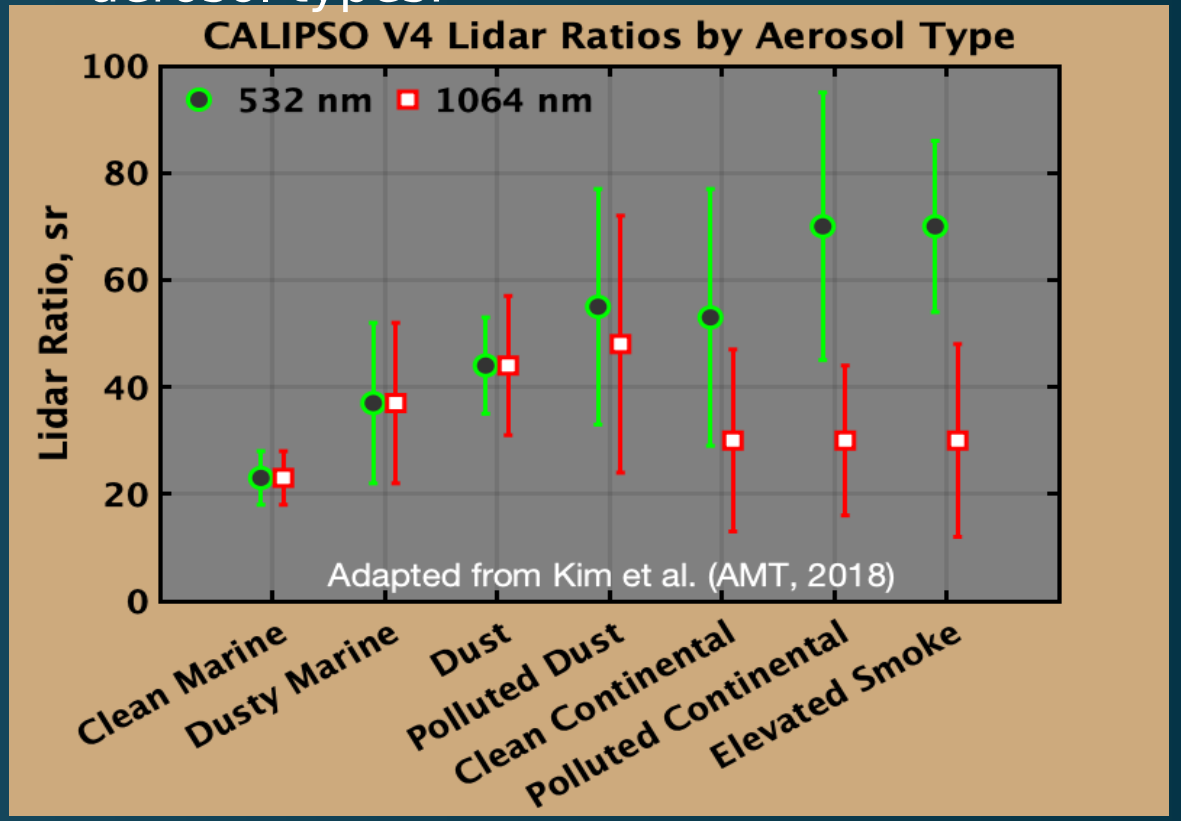
Introduction & motivation for this study

- After 16+ years, the NASA CALIPSO mission will soon retire
- Narrow window of opportunity exists to improve quality of CALIPSO aerosol retrievals by advancing knowledge of aerosol lidar ratios for different aerosol types
- For CALIOP, the elastic backscatter lidar aboard CALIPSO, an aerosol lidar ratio is generally assumed to retrieve vertical profiles of aerosol extinction and subsequently column-integrated AOD

***Goal of this study:** creation of regional and seasonal climatological lidar ratio maps for marine aerosols by leveraging passive aerosol retrievals (MODIS) and global model simulations (GEOS/GOGART)

- Current CALIPSO lidar ratio selection process uses a single lidar ratio for each of the 7 CALIPSO tropospheric aerosol types, with large uncertainties for most aerosol types:



Data & methods

1. Collocate CALIOP backscatter profiles and MODIS AOD retrievals.

2. Perform Fernald (1972) inversion algorithm: use MODIS column-integrated AOD to constrain collocated CALIOP backscatter profiles and infer aerosol lidar ratios.

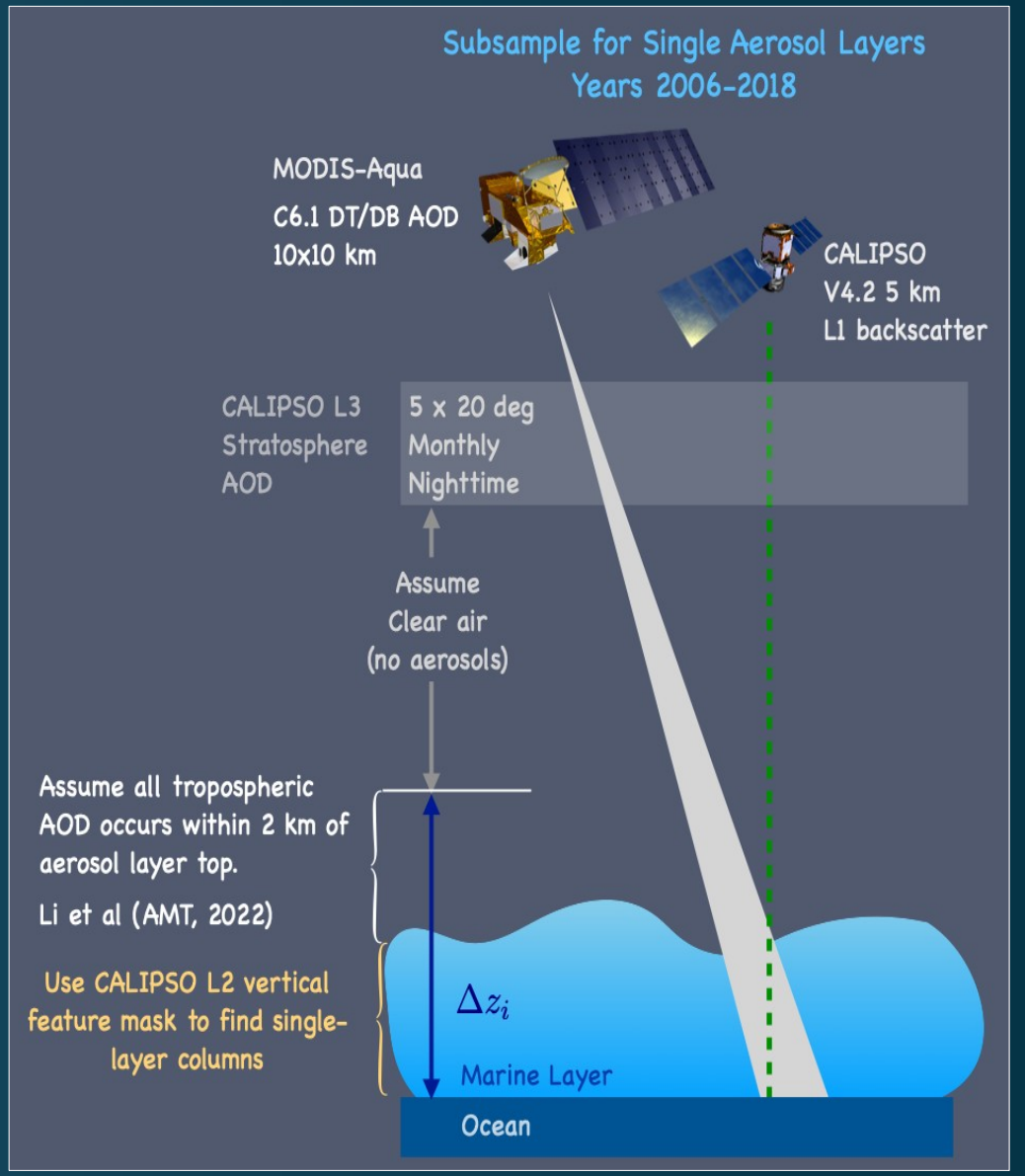
3. Use CALIPSO L3 Stratospheric Aerosol Profile Product to scale lidar ratios to account for stratosphere.

4. Create subset of data for only profiles with CALIOP-classified marine aerosols.

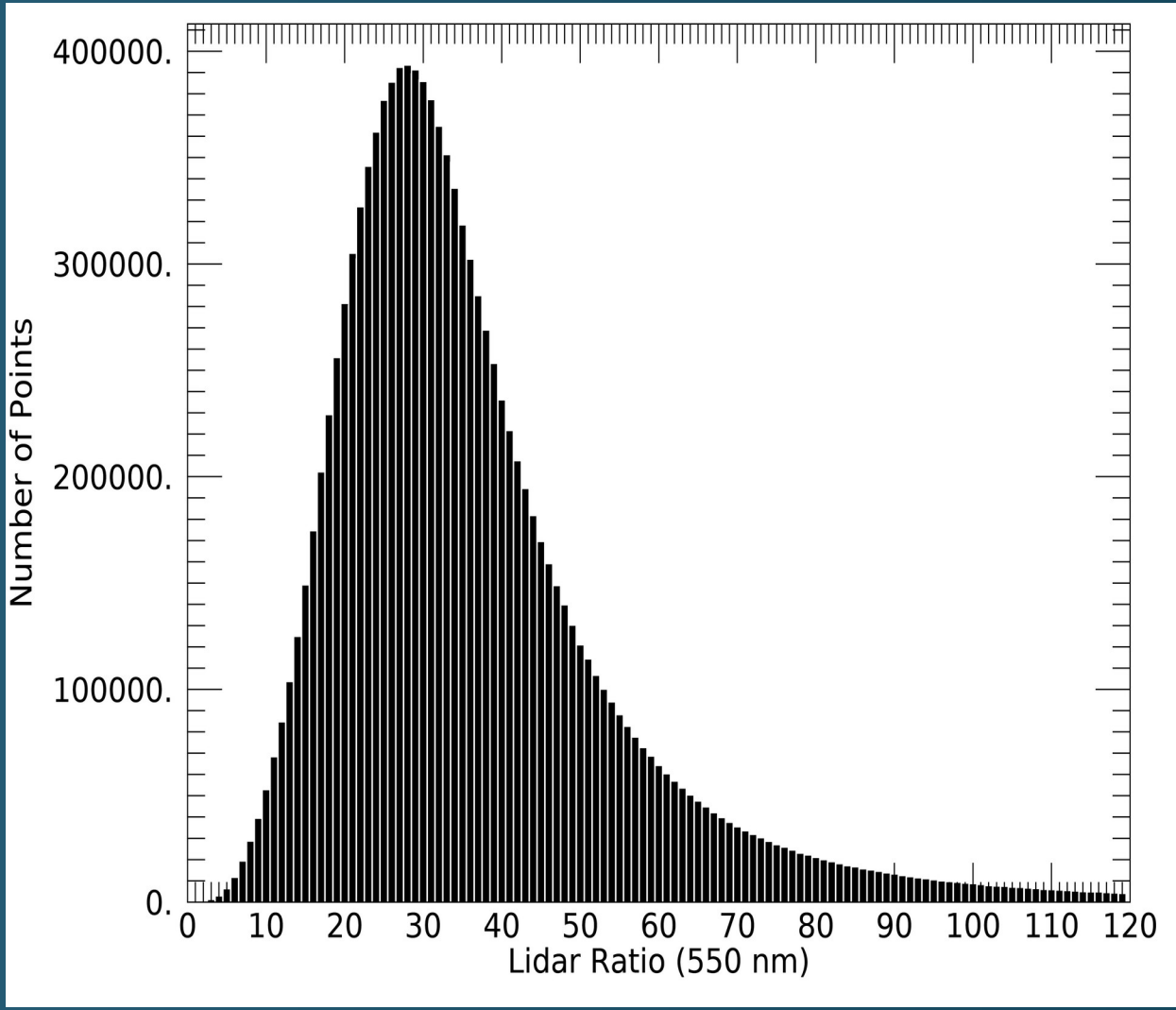
5. Compute sea salt volume fractions (< 2.5 km) from model data.

6. Collocate daily modeled sea salt volume fractions with Fernald-retrieved marine lidar ratios.

7. Develop empirical relationship between modeled sea salt volume fraction and Fernald-retrieved lidar ratios of marine aerosols.



MODIS AOD-constrained lidar ratios for CALIOP-classified marine aerosols (2006-2017)



Number	12,430,815
Minimum	0.000 sr
Maximum	117.95 sr
Mean	31.27 sr
Median	28.34 sr
Standard Deviation	16.24 sr

Sensitivity studies of retrieved lidar ratios

Aerosol Top Height

Aerosol Top Height	≤ 0.5 km	≤ 1.0 km	≤ 1.5 km	≤ 2.0 km
Number	616,498	5,511,503	10,003,988	12,065,528
Minimum	0.002 sr	0.001 sr	0.000 sr	0.000 sr
Maximum	117.53 sr	117.53 sr	117.53 sr	117.53 sr
Mean	37.00 sr	33.29 sr	31.54 sr	31.19 sr
Median	33.25 sr	29.85 sr	28.44 sr	28.25 sr
Standard Deviation	20.30 sr	17.84 sr	16.63 sr	16.22 sr

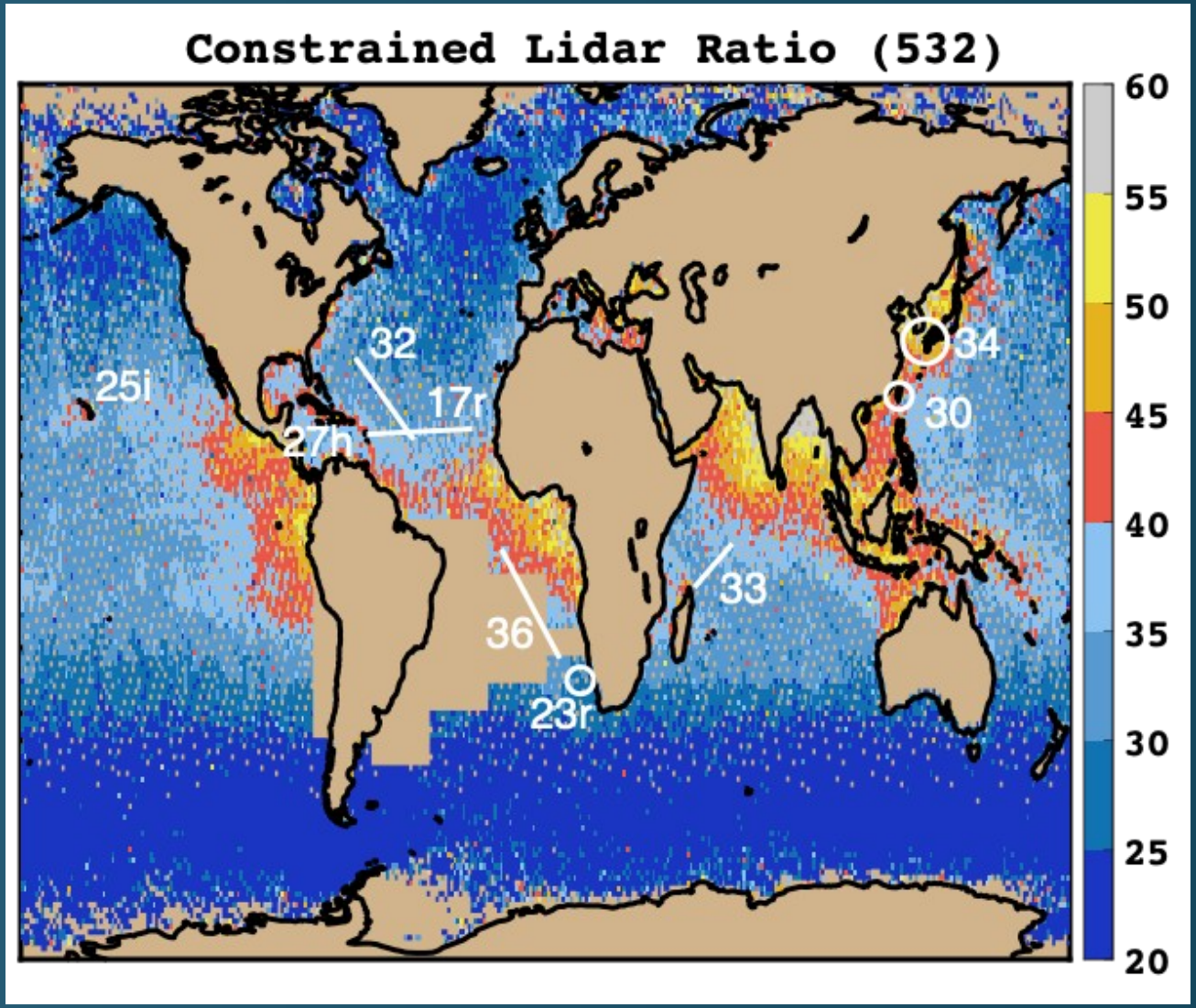
In this study, we consider aerosol top heights of ≤ 2.5 km and all horizontal averages

Horizontal Averaging

Horizontal Averaging	5 km	20 km	80 km
Number	1,214,672	4,389,575	1,998,067
Minimum	0.007 sr	0.002 sr	0.000 sr
Maximum	115.91 sr	117.09 sr	117.53 sr
Mean	23.05 sr	32.35 sr	38.71 sr
Median	21.57 sr	29.91 sr	35.07 sr
Standard Deviation	10.58 sr	16.02 sr	20.65 sr
Mean FMF	0.40	0.45	0.54
Mean SS VF	0.94	0.92	0.88

MODIS AOD-constrained lidar ratios & comparisons to past studies

12-year mean (2006-2017) on 1x1 degree grid



Study	Lidar Ratio (sr)	Method/ Technique
Bohlmann (2018)	23	Raman
Dawson et al. (2015)	26	SODA AOD & CALIOP IAB
Masonis (2003)	25	*In situ*
Rittmeister (2017)	17	Raman
Rogers et al. (2014)	27	HSRL
Schmid (2003)	34	Fernald inversion
Voss (2001)	32; 36	Fernald inversion
Wang (2020)	30	Fernald inversion
Welton (2002)	33	Fernald inversion

Sea salt volume fractions from GEOS/GOCART

12-year mean (2006-2017) on 1x1 degree grid

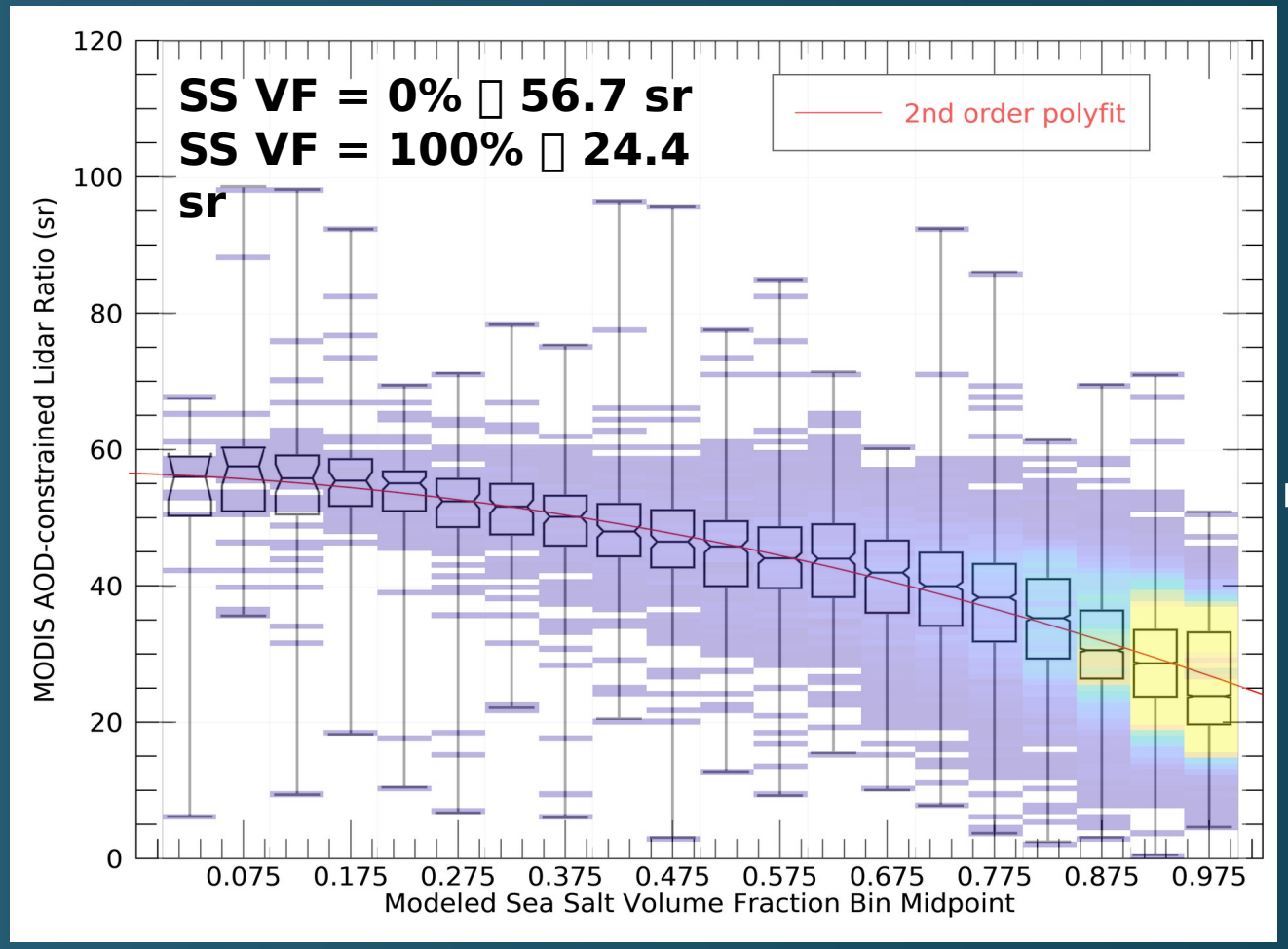
Computation of Modeled Sea Salt Volume Fractions:

- Aerosol Species: SO_4, SO_4v, NH_4a, NO_3 (3 bins), BC, BrC, OC, Dust (5 size bins), Sea salt (5 size bins), but excluding dust for this analysis
- Convert mass mixing ratios (kg kg^{-1}) to volumes (m^3)
- Below 2.5 km, sea salt volume fraction computed as:

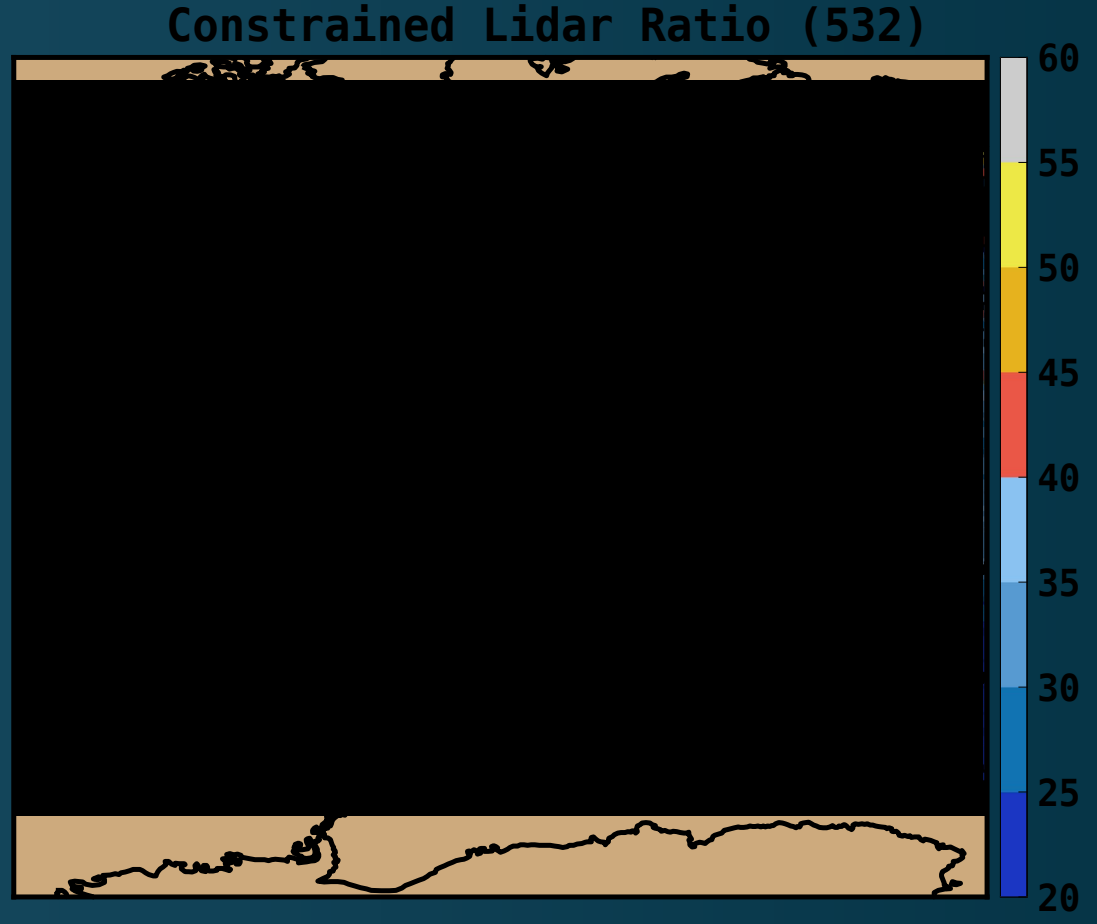
$$\frac{\Sigma(sea\,salt\,volume)}{\Sigma(total\,aerosol\,volume, no\,dust)}$$

Using the model to help construct seasonal lidar ratio maps

Marine lidar ratios as a function of modeled sea salt volume fraction (2006-2017)



Seasonal analysis: 2006-2017 (JJA) lidar ratios (RSE ≤ 10%)



Summary & next steps

- Advantage of approach is using the model to fill gaps & help create climatologies that are consistent with MODIS AOD-constrained retrievals
- Maps will provide improved lidar ratio transitions in coastal regions
- Future efforts include:
  - Seasonal analyses
  - AeroCom multi-model mean for sea salt volume fraction
  - Two-layer aerosol lidar ratios (e.g., smoke over marine)
  - Other CALIOP tropospheric aerosol types
- Helps with final major data products release for CALIPSO (Version 5)
- Provides important aerosol lidar ratio information for future algorithm development of the next space-based lidars (e.g., the AOS elastic backscatter lidar: ALICAT on inclined orbit, AOS-I)

Acknowledgements

- Funding through support of the NASA CALIPSO Project
- CALIPSO data obtained from the NASA LaRC ASDC
- MODIS data obtained from NASA GSFC
- Model data obtained from NASA Discover server (NCCS)

- References:

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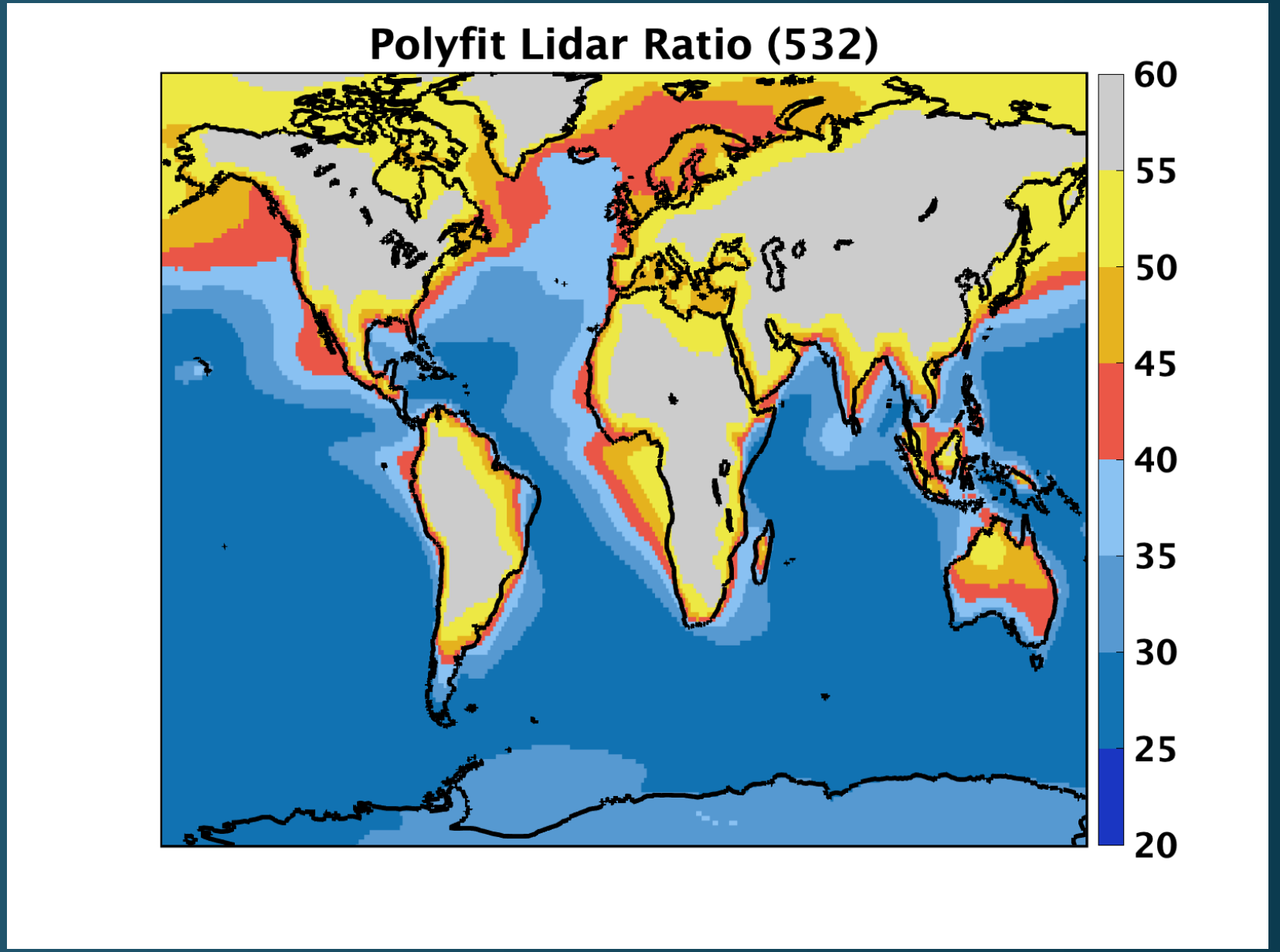
Polyfit Lidar Ratio (532)
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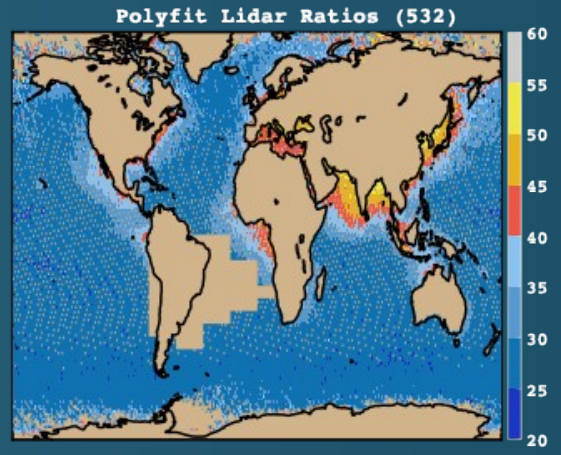
Polyfit Lidar Ratios (532)
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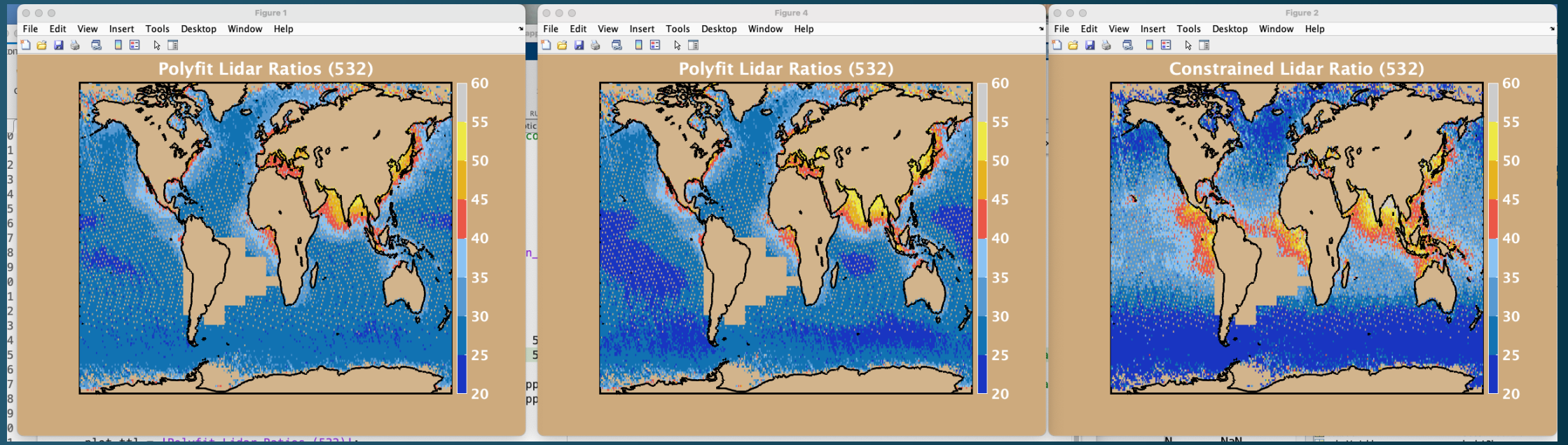
Figure 1
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Polyfit Lidar Ratios (532)
Figure 4
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Polyfit Lidar Ratios (532)
Figure 2
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Constrained Lidar Ratio (532)
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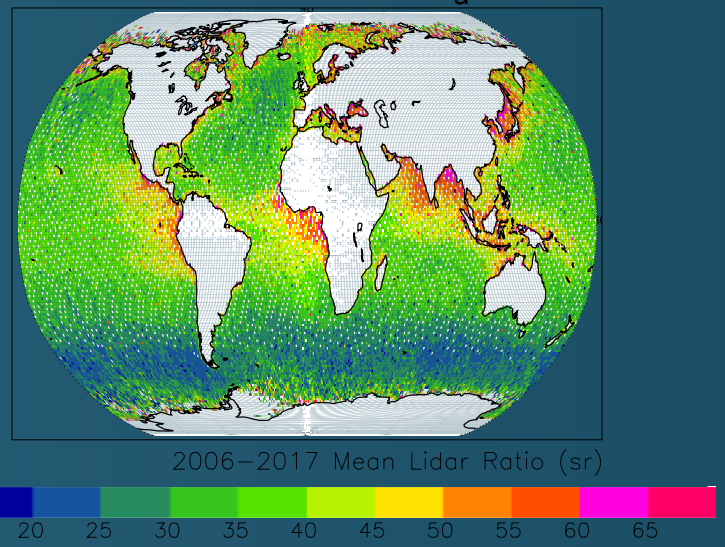
Lidar Ratio (S_a)



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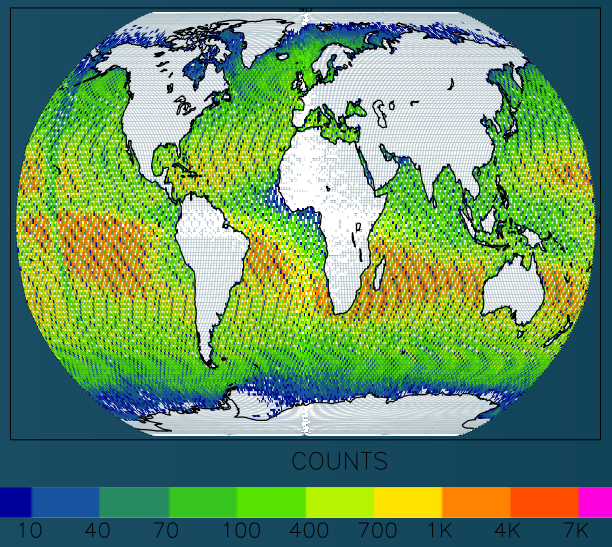
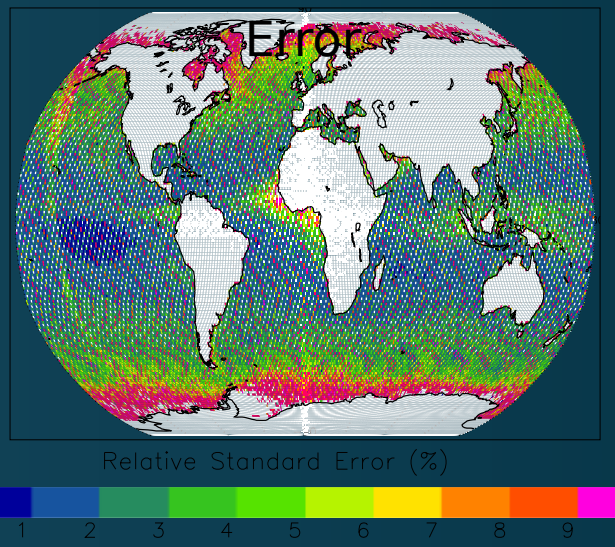
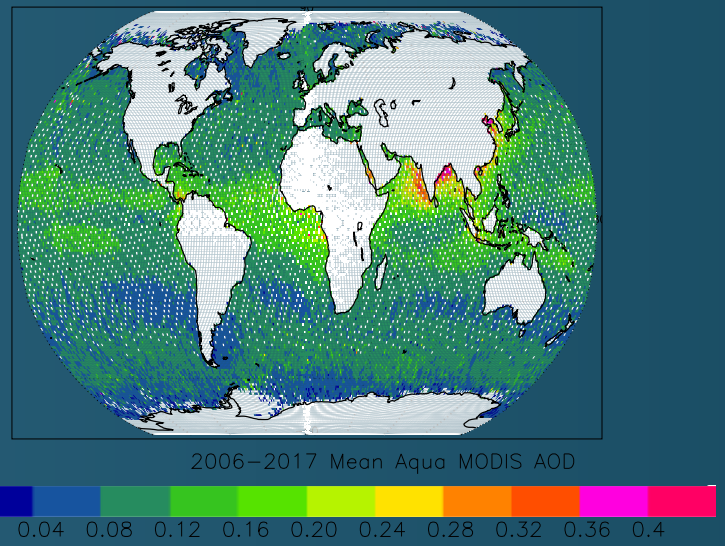


Relative Standard Error

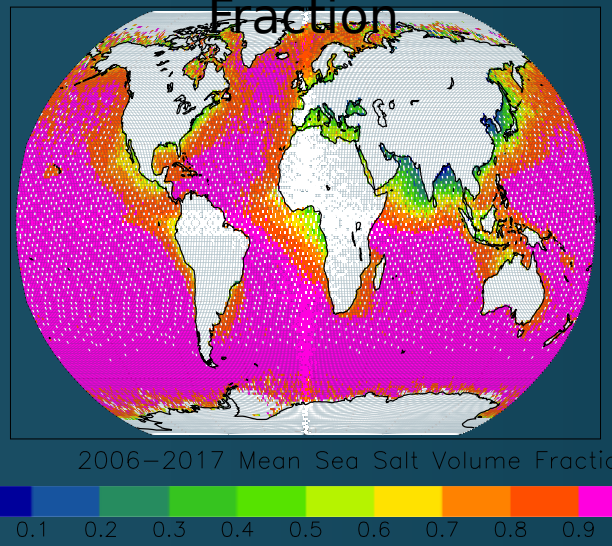


$$\frac{\sigma_l \sqrt{N}}{\langle S_a \rangle}$$

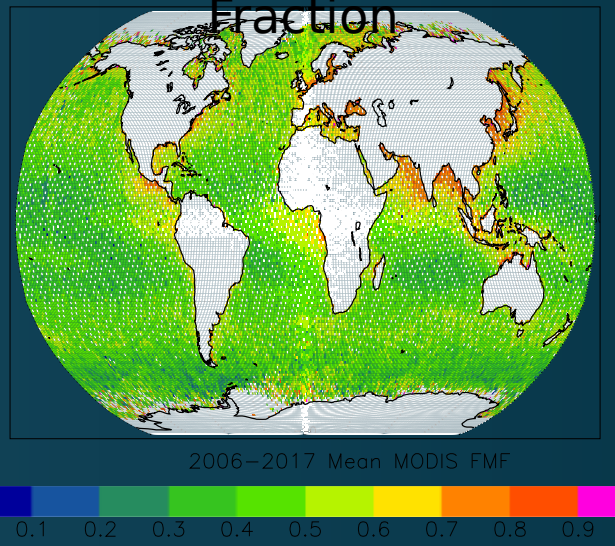
MODIS AOD



Sea Salt Volume Fraction



MODIS Fine Mode Fraction



Using CALIPSO Level 3 Stratospheric Aerosol Product to scale the lidar ratios from constrained retrievals

a. Find CALIOP/MODIS points that fall within each 5 x 20 degree latitude/longitude bin for each month and pull the stratospheric AOD
b. Use the following equation to get the scaled lidar ratio that accounts for stratospheric aerosol loading:

$$S_{scaled} = \frac{\tau_{nostrat}}{\tau_{clmn}} S_{clmn}.$$

$$\tau_{nostrat} = \tau_{clmn} - \tau_{strat}$$

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